Australian Government
Department of Defence
Defence Science and
Technology Organisation

Atmospheric Corrosivity at Australian and Overseas Airbases and Airports

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DSTO-TN-1320

ABSTRACT

Atmospheric corrosivity at 25 airbases and airports in Australia, and 71 overseas airbases and airports, has been measured directly using CLIMAT test samples or predicted using algorithms developed at DSTO. The atmospheric corrosivity at each location is classified as negligible, moderate, moderately severe, severe or very severe. These results will assist aircraft fleet operators to prioritise rinse, wash and maintenance schedules for ADF aircraft based on the time each aircraft has served in the various location corrosivity classifications. Aircraft spending significant time in locations near or at the upper end of atmospheric corrosivity severity can be given preference, if possible, when scheduling rinse, wash and maintenance operations.

RELEASE LIMITATION

Approved for public release

Published by

Maritime Division
DSTO Defence Science and Technology Organisation
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

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Fax: (03) 9626 7999

AR-016-022
July 2014

APPROVED FOR PUBLIC RELEASE

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Executive Summary

Atmospheric corrosivity at airbases and airports is an important factor in Australian Defence Force (ADF) aircraft fleet management as military aircraft spend most of their lifetime on the ground at the airbases and airports. It is to be expected that the more aggressive the corrosivity of the atmosphere at the airbase or airport, the more serious will be the corrosion problems encountered, especially as fleets age and their protective coating systems and corrosion inhibitor treatments deteriorate and become less effective.

The CLIMAT environmental corrosion test has been used by corrosion investigators in Australia, UK, Canada, New Zealand, US, Europe, South Africa and South America to measure atmospheric corrosivity. The test consists of an aluminium wire wrapped around a copper bolt exposed in the atmosphere for three months; the weight loss of the wire after this time, expressed as a percentage, is taken as a measure of atmospheric corrosivity. An average corrosivity can be obtained by exposing test samples throughout the year.

Collecting CLIMAT weight loss data is time consuming and expensive. The Tactical Fighter Systems Program Office at RAAF Williamtown sponsored a project at the Defence Science and Technology Organisation to develop Geographic Corrosivity Index algorithms that could predict, based on climate and geographic data, the results of CLIMAT testing at a given site with a reasonable degree of accuracy. These algorithms have been used to predict the atmospheric corrosivity at 96 airbases and airports around the world, including 25 in Australia, 45 in the US and 9 in Canada, as well as others in New Zealand, Asia, Europe and the Middle East.

All of these predicted CLIMAT results have been brought together in this report, as well as actual measured CLIMAT test results where available. On the basis of these results, each airbase or airport has been assigned one of the following atmospheric corrosivity classifications:

Negligible
Moderate
Moderately severe
Severe
Very severe

Categorising bases and airports in this way can assist in predicting the severity of corrosion problems that are likely to occur for ADF aircraft stationed at a particular base, and can assist ADF fleet managers to determine optimum schedules for aircraft rinsing, washing and maintenance actions.

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Abbreviations/Acronyms

AAC	Army Aviation Centre
AB	Air Base
ADF	Australian Defence Force
AFB	Air Force Base
Al	aluminium
ANGB	Air National Guard Base
ARB	Air Reserve Base
ARS	Air Reserve Station
AS	Air Station
CFB	Canadian Forces Base
CLIMAT	CLassify Industrial and Marine ATmospheres
Cu	copper
DSTO	Defence Science and Technology Organisation
GCI	Geographic Corrosivity Index
HMAS	Her Majesty's Australian Ship
ISO	International Organisation for Standardization
JARS	Joint Air Reserve Station
JNGB	Joint National Guard Base
NAS	Naval Air Station
NAWS	Naval Air Weapons Station
NSF	Naval Support Facility
R	Correlation coefficient
RAAF	Royal Australian Air Force
RAF	Royal Air Force
RMAF	Royal Malaysian Air Force
RNZAF	Royal New Zealand Air Force
RTAFB	Royal Thai Air Force Base
SDR	salt deposition rate
TFSPO	Tactical Fighter Systems Program Office
TOW	time of wetness
UNLB	United Nations Logistics Base
UK	United Kingdom of Great Britain and Northern Ireland
US	United States of America

1. Introduction

The Defence Science and Technology Organisation (DSTO) has measured the atmospheric corrosivity at several airbases and airports in Australia over a number of years using CLIMAT[1] test samples, consisting of aluminium wire wound on a copper bolt (Al/Cu CLIMAT) [1]. The Al/Cu CLIMAT test samples were exposed for three months, and the weight loss of the aluminium wire measured. The weight loss is expressed as a percentage, and is called the CLIMAT indice. This indice is taken as a measure of atmospheric corrosivity. Test samples were exposed throughout the year, so that a representative average annual weight loss for the aluminium wire was obtained [2].

Depending on the average CLIMAT indice, the atmospheric corrosivity has been classified as "negligible" (indice 0-1), "moderate" (indice 1-2), "moderately severe" (indice 2-4), "severe" (indice 4-7) and "very severe" (indice >7) [3]. As military aircraft spend most of their time on the ground where they are exposed to the atmosphere of the base or airport, the corrosivity of the atmosphere is expected to play a dominant role in the incidence and progress of corrosion occurring on aircraft stationed at the base or airport, especially as aircraft age and their protective systems deteriorate. Categorising bases and airports in this way assists in predicting the seriousness and progress of corrosion problems that are likely to occur on aircraft stationed at a particular base or airport, and can assist aircraft fleet managers to determine optimum schedules for rinsing, washing and maintenance actions.

Collecting CLIMAT weight loss data at bases and airports is a time consuming and expensive exercise. It is known that salt or chloride deposition rate (CDR) and time of wetness (TOW) are two key factors influencing corrosion. CDR is determined by the amount of marine aerosol that is blown inland from the sea and TOW is the period of time when a metal surface is wetted so that corrosion can occur. The Tactical Fighter Systems Program Office (TFSPO) at RAAF Williamtown sponsored a project at DSTO to develop an algorithm that could predict the Al/Cu CLIMAT indice at any particular site, based on publicly available climate and geographic data.

This report summarises the development of the predictive CLIMAT indice algorithm, called the Geographic Corrosivity Index (GCI). This algorithm and derivative variants have been used to predict Al/Cu CLIMAT results at Australian bases and airports, and at several overseas bases and airports [5,6,7,8]. All measured average Al/Cu CLIMAT test sample results available to DSTO and all of the GCI predicted results are brought together in this report.

[1] CLassify Industrial and Marine ATmospheres

2. Summary of Geographic Corrosivity Index Development

About 35 years ago, the International Organization for Standardization (ISO) began a major effort to identify the key factors that cause atmospheric corrosion and to classify atmospheric environments, resulting in the standard ISO 9223 [4]. This standard identifies time of wetness (TOW) and two atmospheric pollutants, sulphur dioxide and airborne salinity, as the key corrosion factors, and classifies atmospheres into five categories of corrosivity based on the values of these three variables. More recent work indicates that this approach is somewhat simplistic [9], but these three variables are still very important in determining the degree of corrosion that occurs. As an alternative in the standard, the corrosivity of a site can be established by actual corrosion rate measurements of standard specimens.

In the regions of interest to the RAAF, levels of sulphur dioxide pollutants in the atmosphere have either been reduced to such an extent over the last 25 years, or were already so low, that the key factors in ISO 9223 have effectively been reduced to TOW and airborne salinity. Unfortunately TOW and airborne salinity (usually measured as chloride deposition rate or CDR) are not readily measured without specialised equipment and techniques. DSTO has considerable atmospheric corrosion rate data from weight loss measurements for CLIMAT specimens and salt deposition rate data or CDR (salt candles [10]) for several ADF bases, gathered over recent years. Using these data, a simple empirical algorithm was developed that provided a good correlation with weight loss data obtained from aluminium-on-copper-bolt CLIMAT (Al/Cu CLIMAT) specimens [5].

The algorithm was called the Geographic Corrosivity Index (GCI), and took the following form:

$$\mathrm{GCI} = \mathrm{DR} \times \mathrm{WR} \times \mathrm{GR} \times \mathrm{TR} \tag{1}$$

where:

- DR is a distance from the coast rating
- WR is a wind rating
- GR is a geographic coastal rating that takes into account the fetch, which is the distance that winds blow over the sea before reaching land, and
- TR is a TOW rating, calculated from temperature and relative humidity data

The combined $\mathrm{DR} \times \mathrm{WR} \times \mathrm{GR}$ ratings estimate the chloride deposition rate. The various ratings were based on average annual values, producing an average GCI.

CLIMAT test samples are only exposed for three months, so DSTO exposed successive test samples throughout the year. These results clearly showed that there were considerable seasonal variations in atmospheric corrosivity at most sites. When corresponding quarterly climate data were used with each individual CLIMAT result in the algorithm, it became apparent that an improved correlation could be obtained by making some modifications to the various ratings in the algorithm:

- TOW was changed from a ranking to actual calculated hours of wetness, which better reflected the changes in TOW
- The wind ranking was replaced by a wind aggregate which took into account wind direction as well as wind speed, i.e. only off-sea winds were included.
- Some of the components of the algorithm were raised to fractional powers.

The improved algorithm [6] took the following form, with WA being a wind aggregate rating and GCIM being the Geographic Corrosivity Index (Monthly):

$$\mathrm{GCIM} = \mathrm{DR} \times \mathrm{GR} \times \mathrm{WA}^{0.26} \times \mathrm{TR}^{0.38} \quad (2)$$

This algorithm was able to model quarterly variations in CLIMAT results with considerable accuracy [6]. The algorithm was also used to calculate GCIA, an annualised version using annual average climate data.

To increase confidence in the application of the index to a wider range of geographic and climatic conditions, the correlation between the GCIA and weight loss data from aluminium alloy coupons exposed in the open at 38 sites in the US, Europe, Asia and the Pacific and Indian Ocean regions was investigated. Initially the correlation was only moderate. Modifications were made to the GCIA that improved the correlation considerably for sites within 200 km of the coast [7]:

- Greater weight was given to sites near the coast
- More wind directions were considered
- Fetch was associated with each individual wind direction

The modified algorithm, ModGCIA, was then applied to the six Australian, five Canadian, three New Zealand sites and one US site within 200 km of the coast which had both Al/Cu CLIMAT data and appropriate climate data, and the optimised correlation took the following form, with FR being a fetch rating:

$$\mathrm{ModGCIA} = \mathrm{TR}^{2.26} \times \sum(\mathrm{DR} \times \mathrm{FR} \times \mathrm{WA}^{0.34}) \quad (3)$$

where the sum Σ is taken over the individual wind directions.

The relationship between ModGCIA and the fifteen Australian and overseas bases within 200 km of the coast for which average CLIMAT data was available is shown in Figure 1.

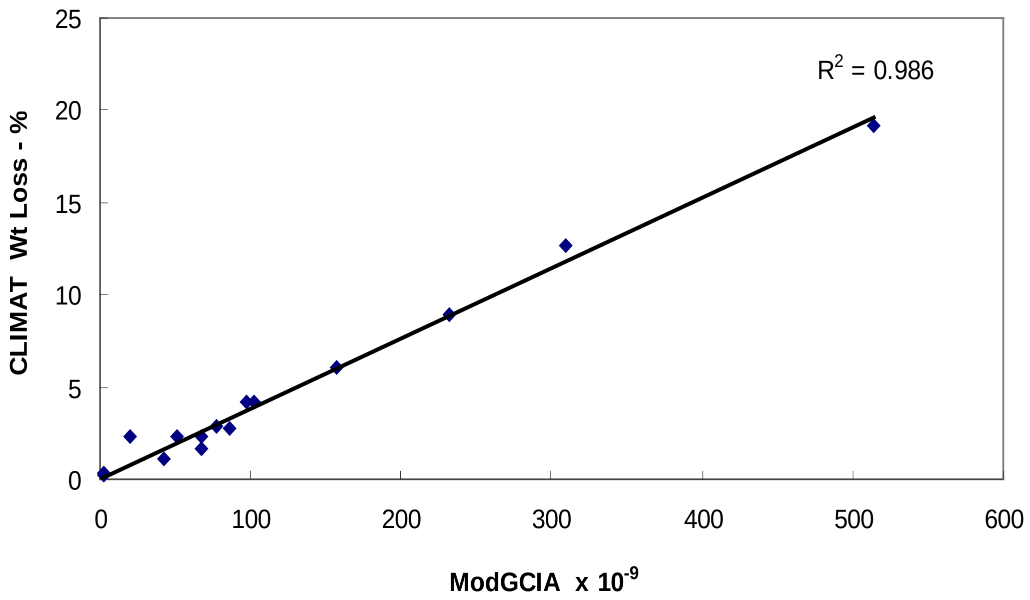

Figure 1 Relationship between ModGCIA and Al/Cu CLIMAT weight loss data for 15 Australian and overseas bases within 200 km of the coast [7].

There was a very strong linear correlation between the ModGCIA algorithm and the average Al/Cu CLIMAT results (correlation coefficient R^2=0.986), as can be seen in Figure 1. This relationship is described by the following algorithm:

$$\text{Al/Cu CLIMAT} = 0.0382 \times \text{ModGCIA} \times 10^{-9} \qquad (4)$$

Algorithm (4) was not very successful at modelling Al/Cu CLIMAT results at distances greater than 200 km from the coast. A reasonably successful simpler algorithm was developed that did not include wind or geographic ratings, as they would seem to be less relevant at these considerable distances from the coast:

$$\text{Al/Cu CLIMAT} = 1.784 \times \text{TOW}^{0.49} / \text{distance from the coast} \qquad (5)$$

Algorithms (2), (4) and (5) have been used to classify the atmospheric corrosivity at 25 airbases and airports within Australia, and at many airbases and airports overseas. The results are shown for airbases and airports in Australia (Appendix A), the United States (Appendix B), Canada and New Zealand (Appendix C) and Asia, the Middle East and Europe (Appendix D). Classifications were based on the Doyle and Wright AL/Cu CLIMAT indice ranges shown in Table 1. Where available, average measured Al/Cu CLIMAT results are also presented.

The details of the computation of the individual parameters in these models are documented in previous reports [5,6,7].

3. Atmospheric Corrosion Rate Classification

ISO 9223 classifies the corrosion rates of aluminium into five categories – C1, C2, C3, C4 and C5 [4]. Doyle and Wright [3], from their experience using CLIMAT results from a variety of atmospheric environments have given more useful descriptive names to five corrosion rate categories — negligible, moderate, moderately severe, severe and very severe. The later classification is open ended in terms of corrosion rate whereas the ISO 9223 classification has an upper limit that is unrealistically low. The two classifications are detailed in Table 1. Note that the CLIMAT corrosion rates have been converted from the helical aluminium wire CLIMAT test results to equivalent flat aluminium sheet results, using a formula devised by Doyle and Wright [3], for comparison with the ISO 9223 rates which are for flat aluminium sheet. The Doyle and Wright classification, as specified in Table 1, is shown in the appendices for each of the airbases and airports.

Table 1 Aluminium corrosion rates and classification from ISO 9223:1992 [4] and Doyle and Wright [3]

ISO 9223		Doyle & Wright		
Classification	**Corrosion Rate $g/m^{-2}a^{-1}$**	**Classification**	**Al/Cu CLIMAT Indice Range**	**Corrosion Rate $g/m^{-2}a^{-1}$**
C1	Negligible	Negligible	0 to 1	0 – 1.2
C2	≤ 0.6	Moderate	>1 to 2	1.2 – 2.7
C3	0.6 to ≤ 2	Moderately severe	>2 to 4	2.7 – 5.9
C4	2 to ≤ 5	Severe	>4 to 7	5.9 – 10.6
C5	5 to ≤ 10	Very severe	> 7	> 10.6

4. Conclusions

Three algorithms, equations (2), (4) and (5) above, have been used to predict the corrosivity of the atmosphere, as measured by Al/Cu CLIMAT specimens, at 25 Australian airbases and airports, and at many overseas airbases and airports. This report brings together measured average Al/Cu CLIMAT test sample results available to DSTO, and all of the predicted results using the GCI and its variants. These results are shown in the various appendices. The atmospheric corrosivity classification devised by Doyle and Wright [3] is also shown. These results will assist ADF aircraft fleet operators to schedule optimum rinse, wash and maintenance actions.

5. Acknowledgement

It is acknowledged that many of the CLIMAT and salt candle values used in GCI calculations came from work performed by Elaine Duxbury (DSTO).

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Appendix A: Measured and Predicted Atmospheric Corrosivity CLIMAT Indices for Australian Bases and Airports

Base or Airport	State or Territory	Average Measured CLIMAT (% wt. loss)	GCI Predicted CLIMAT (% wt. loss)	Atmospheric Corrosivity Classification
Australia				
Alice Springs	NT	-	0.1 (2)	Negligible
RAAF Amberley	Qld	1.7	1.8 (4)	Moderate
Canberra	ACT	-	0.22 (2)	Negligible
Christmas Island	Indian Ocean	-	3.5 (4)	Moderately severe
Cocos Island	Indian Ocean	-	7.9 (4)	Very severe
RAAF Curtin	WA	-	0.32 (4)	Negligible
RAAF Darwin	NT	1.1	1.1 (4)	Moderate
RAAF East Sale	Vic	2.8	2.9 (4)	Moderately severe
RAAF Edinburgh	SA	2.7	3.0 (4)	Moderately severe
Hobart	Tas	-	1.3 (2)	Moderate
RAAF Laverton	Vic	-	1.7 (2)	Moderate
RAAF Learmonth	WA	-	0.84 (4)	Negligible
Mt Isa	Qld	-	0.11 (2)	Negligible
Norfolk Island	Pacific Ocean	-	8.9 (4)	Very severe
NAS Nowra	NSW	2.3	2.3 (4)	Moderately severe
Oakey AAC	Qld	-	0.94 (2)	Negligible
RAAF Pearce	WA	3.4	2.6 (4)	Moderately severe
RAAF Richmond	NSW	2.4	2.5 (4)	Moderately severe
Rockhampton	Qld	-	1.9 (4)	Moderate
RAAF Scherger	Qld	1.6	1.4 (4)	Moderate
HMAS Stirling	WA	10.1	10.0 (4)	Very severe
RAAF Tindal	NT	0.27	0.27 (5)	Negligible
RAAF Townsville	Qld	2.7	3.3 (4)	Moderately severe
RAAF Williamtown	NSW	4.1	4.3 (4)	Severe
Woomera Airfield	SA	-	0.21 (4)	Negligible

Superscript (2): GCI CLIMAT predicted using algorithm (2)
Superscript (4): GCI CLIMAT predicted using algorithm (4)
Superscript (5): GCI CLIMAT predicted using algorithm (5)

Appendix B: Predicted Atmospheric Corrosivity CLIMAT Indices for United States Bases and Airports

Base or Airport	State or Territory	GCI Predicted CLIMAT (% wt. loss)	Atmospheric Corrosivity Classification
United States			
Altus AFB	Oklahoma	0.09 (5)	Negligible
Andersen AFB	Guam	1.9 (4)	Moderate
Athens Airport	Georgia	0.31 (5)	Negligible
Atlantic City	New Jersey	0.49 (4)	Negligible
Barksdale AFB	Louisiana	0.32 (5)	Negligible
Charleston AFB	South Carolina	2.0 (4)	Moderately severe
NAWS China Lake	California	0.01 (5)	Negligible
NAS Corpus Christi	Texas	3.4 (4)	Moderately severe
Daytona Beach	Florida	4.6 (4)	Severe
NSF Diego Garcia	Indian Ocean	4.3 (4)	Severe
Dover AFB	Deleware	1.1 (4)	Moderate
Eareckson AS	Alaska	1.5 (4)	Moderate
Eglin AFB	Florida	2.5 (4)	Moderately severe
Eielson AFB	Alaska	0.12 (5)	Negligible
Elmendorf AFB	Alaska	0.05 (4)	Negligible
Fairchild AFB	Washington	0.16 (5)	Negligible
Fort Smith AFB	Arkansas	0.15 (5)	Negligible
Fresno ANGB	California	0.06 (4)	Negligible
Hickam AFB	Hawaii	6.4 (4)	Severe
Homestead ARB	Florida	0.23 (4)	Negligible
Hurlburt Field AFB	Florida	3.2 (4)	Moderately severe
Jackson ANGB	Mississippi	0.45 (5)	Negligible
Kennedy Space Centre	Florida	18.7* (4)	Very severe
Langley AFB	Virginia	2.3 (4)	Moderately severe
Malmstrom AFB	Montana	0.06 (5)	Negligible
March ARB	California	0.06 (4)	Negligible
Mc Chord AFB	Washington	0.43 (4)	Negligible
McDill AFB	Florida	3.0 (4)	Moderately severe
McEntire JNGB	South Carolina	0.03 (4)	Negligible
McGuire AFB	New Jersey	0.70 (4)	Negligible
Minneapolis St Paul JARS	Minnesota	0.07 (5)	Negligible
Nellis AFB	Nevada	0.05 (5)	Negligible
NAS North Island	California	5.5 (4)	Severe

Superscript (4): GCI CLIMAT predicted using algorithm (4)
Superscript (5): GCI CLIMAT predicted using algorithm (5)

* Measured average Al/Cu CLIMAT: 19.2

Appendix B (continued):

Base or Airport	**State or Territory**	**GCI Predicted CLIMAT (% wt. loss)**	**Atmospheric Corrosivity Classification**
Pease ANGB	New Hampshire	0.45 (4)	Negligible
Pittsburg ARS	Pennsylvania	0.18 (5)	Negligible
Robins AFB	Georgia	0.37 (5)	Negligible
Shaw AFB	South Carolina	0.09 (4)	Negligible
Sioux City ANGB	Iowa	0.06 (5)	Negligible
Springfield ANGB	Illinois	0.09 (5)	Negligible
Tinker AFB	Oklahoma	0.11 (5)	Negligible
Toledo ANGB	Ohio	0.12 (5)	Negligible
Travis AFB	California	0.41 (4)	Negligible
Tulsa ANGB	Oklahoma	0.11 (5)	Negligible
Wake AFB	Pacific Ocean	5.0 (4)	Severe
Wright –Patterson AFB	Ohio	0.12 (5)	Negligible

Superscript (4): GCI CLIMAT predicted using algorithm (4)
Superscript (5): GCI CLIMAT predicted using algorithm (5)

Appendix C: Measured and Predicted Atmospheric Corrosivity CLIMAT Indices for Canadian and New Zealand Bases and Airports

Base or Airport	Province or Region	Average Measured CLIMAT (% wt. loss)	GCI Predicted CLIMAT (% wt. loss)	Atmospheric Corrosivity Classification
Canada				
CFB Bagotville	Quebec	0.32	0.11 (4)	Negligible
CFB Cold Lake	Alberta	-	0.07 (5)	Negligible
CFB Comox	BC	2.31	1.9 (2)	Moderately severe
CFB Goose Bay	Labrador	0.17	0.62 (2)	Negligible
CFB Greenwood	NB	1.62	1.3 (2)	Moderate
Mirabel	Quebec	-	0.23 (4)	Negligible
CFB North Bay	Ontario	0.61	0.16 (5)	Negligible
CFB Trenton	Ontario	0.20	0.24 (5)	Negligible
CFB Winnipeg	Manitoba	0.10	0.09 (5)	Negligible
New Zealand				
Invercargill	Southland	9.2	9.8 (4)	Very severe
RNZAF Ohakea	Manawatu	6.1	6.0 (4)	Severe

Superscript (2): GCI CLIMAT predicted using algorithm (2)
Superscript (4): GCI CLIMAT predicted using algorithm (4)
Superscript (5): GCI CLIMAT predicted using algorithm (5)

Appendix D: Predicted Atmospheric Corrosivity CLIMAT Indices for Asian, Middle Eastern and European Bases and Airports

Base or Airport	Country	GCI Predicted CLIMAT (% wt. loss)	Atmospheric Corrosivity Classification
Asia			
Brunei	Brunei	10.8 (4)	Very severe
RMAF Butterworth	Malaysia	4.3 (4)	Severe
Denpasar	Indonesia	9.9 (4)	Very severe
Honiara	Solomon Islands	8.6 (4)	Very severe
Jakarta	Indonesia	4.0 (4)	Severe
Khorat RTAFB	Thailand	0.48 (5)	Negligible
RMAF Kuantan	Malaysia	5.0 (4)	Severe
Paya Lebar AB	Singapore	6.0 (4)	Severe
Taipei	Formosa	3.2 (4)	Moderately severe
Middle East			
Al Udeid AB	Qatar	0.09 (4)	Negligible
Europe			
Aviano AB	Italy	0.14 (4)	Negligible
UNLB Brindisi	Italy	4.2 (4)	Severe
RAF Brize Norton	UK (Oxford)	0.84 (4)	Negligible
RAF Mildenhall	UK (Suffolk)	1.5 (4)	Moderate
RAF Valley	UK (North Wales)	10.4 (4)	Very severe

Superscript (4): GCI CLIMAT predicted using algorithm (4)
Superscript (5): GCI CLIMAT predicted using algorithm (5)

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. DLM/CAVEAT (OF DOCUMENT)

2. TITLE	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)
Atmospheric Corrosivity at Australian and Overseas Airbases and Airports	Document (U) Title (U) Abstract (U)

4. AUTHOR(S)	5. CORPORATE AUTHOR
J C Bitcon	DSTO Defence Science and Technology Organisation 506 Lorimer St Fishermans Bend Victoria 3207 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TN-1320	AR-016-022	Technical Note	July 2014

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
2013/1201467/1	AIR 07/101	TFSPO	11	10

13. DSTO Publications Repository	14. RELEASE AUTHORITY
http://dspace.dsto.defence.gov.au/dspace/	Chief, Maritime Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for Public Release

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CITATION IN OTHER DOCUMENTS Yes

18. DSTO RESEARCH LIBRARY THESAURUS

Aluminium, Aircraft, Algorithm, Atmospheric corrosion, Environmental factors

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Atmospheric corrosivity at 25 airbases and airports in Australia, and 71 overseas airbases and airports, has been measured directly using CLIMAT test samples or predicted using algorithms developed at DSTO. The atmospheric corrosivity at each location is classified as negligible, moderate, moderately severe, severe or very severe. These results will assist aircraft fleet operators to prioritise rinse, wash and maintenance schedules for ADF aircraft based on the time each aircraft has served in the various location corrosivity classifications. Aircraft spending significant time in locations near or at the upper end of atmospheric corrosivity severity can be given preference, if possible, when scheduling rinse, wash and maintenance operations.